

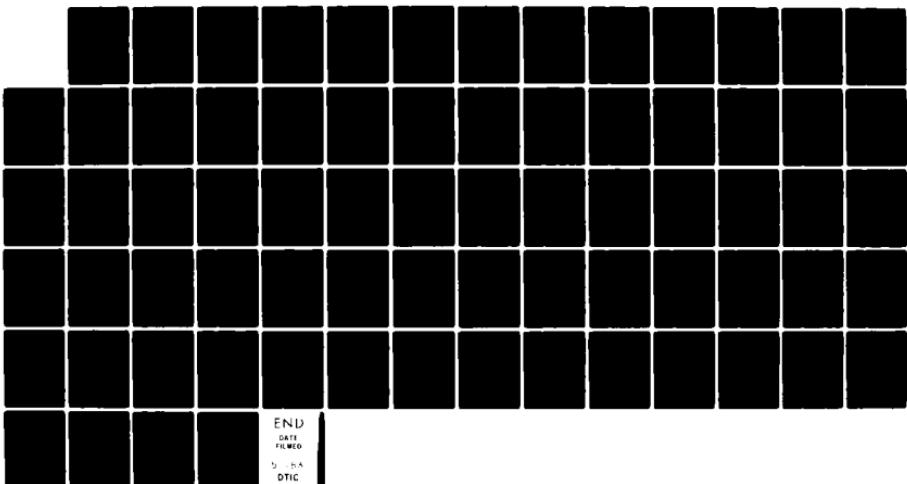
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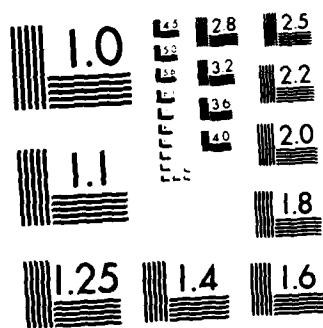
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Shallow Water Acoustics Workshop, 1983

University of Southern Mississippi
Gulf Park Campus, MS 39560

9-11 February 1983

Sponsored by the Office of Naval Research

APL-UW 1-83
February 1983

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**University of Southern Mississippi
Gulf Park Campus, MS 39560**

9-11 February 1983

Sponsored by the Office of Naval Research

**APL-UW 1-83
February 1983**

Prepared by

Morris Schulkin for the Workshop Steering Committee:

**P.H. Rogers, ONR, Chairman; A.I. Eller, NRL, Co-Chairman;
M. Schulkin, APL-UW, Executive Secretary; D.L. Bradley, ONR;
W.A. Kuperman, NORDA; W.B. Moseley, NRL; T. Warfield, ONR;
R.S. Winokur, ONR; Capt. E.T. Young, Jr., OP-952.**



UNIVERSITY OF WASHINGTON • APPLIED PHYSICS LABORATORY

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FOREWORD

Over the years a large amount of money and effort has gone into shallow water acoustics research. Yet it has been difficult to develop optimal ASW systems for the shallow water environment with its complex oceanography and bottom geological substructure, great shipping density and other commercial activity, sunken artifacts, and important biological acoustical effects.

The research has included measurements and theory over a wide range of frequencies and locations. Charges and discrete frequency sources including pulses and cw have been used for measuring the propagation characteristics including the bottom loss. In general, a frequency of least propagation loss has been found to exist, the frequency's value depending on location and season. Reverberation and scattering measurements have been made for fixed-source, fixed-receiver installations as well as for moving sources and receivers. There is also a greater knowledge of the acoustic properties of shallow water sediments and a better understanding of the propagation of shear waves in the bottom. Powerful modeling techniques are now available using normal modes, fast Fourier programs, and/or the parabolic differential equation solutions to the wave equation.

Although it has been recognized that shallow water systems emphasize different acoustics aspects than deep water systems, most of the shallow water applications and developments have used deep water detection systems. Thus a point has been reached in Naval system development where there is a recognized need for a wider knowledge base providing options for better use of existing systems or the design of new systems as required.

This is the setting in which two Shallow Water Acoustics Workshops were held for the purpose of defining the need for progress and the best direction in which to proceed. Previous symposia and conferences on shallow water acoustics have been held intermittently, but their scope has been local and they have been of the information exchange variety. The present Workshops have been comprehensive and focused in the attempt to define a basic research program important for all fleet needs. This document reports on the second of the Workshops.

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1. WORKSHOP OVERVIEW

1.1 Introduction

A Shallow Water Acoustics Workshop (1983) was held at the University of Southern Mississippi Gulf Park Campus, 9-11 February 1983, under the sponsorship of the Office of Naval Research (Code 425UA, Dr. P.H. Rogers). The Workshop was hosted by the Naval Ocean Research and Development Activity (NORDA; Code 320, Dr. W.A. Kuperman) and organized by Dr. Morris Schukin of the Applied Physics Laboratory of the University of Washington under an ONR Grant. The purpose of the Workshop was to help develop a research program plan in shallow water acoustics.

As part of this process a classified workshop (1982) was held to assess Navy requirements and to identify areas where additional research was needed. An unclassified summary of the conclusions and recommendations of that Workshop is contained in Appendix A. Based on this report, two problem areas were selected to be the focus of the proposed program. The objective of this Workshop was to formulate an approach to answering the following questions.

1. *Characterization of the Acoustic Environment*

- a. What properties of the bottom, surface and water column are required to characterize the propagation and scattering of acoustic signals, including fluctuations, coherence and directivity?
- b. To what precision and in what form must these environmental properties be given?
- c. What survey techniques can be used to obtain these properties and how can they be validated? Possibly a set of techniques responding to increasing layers of detail would be advantageous.

2. *Acoustic Target Classification Techniques*

Shallow water scenarios often are characterized by an abundance of commercial shipping, artifacts on the seabed, or other sources of false contacts. Hence, a crucial feature of a system is its ability to classify and distinguish the several detections it receives. The thrust of this topic is to explore the basic physics of various classification techniques such as source depth estimation, frequency discrimination, and azimuthal bearing resolution. Specific questions that might be addressed include:

- a. How can submerged and nonsubmerged targets be distinguished in shallow water either actively or passively?

- b. How can targets of interest be distinguished from shipwrecks, schools of fish, whales, debris, etc.? How can the temporal and spectral characteristics of the echo be exploited to classify targets independently of target aspect?
- c. How can low Doppler targets be detected in the presence of surface reverberation?
- d. How can pulse design be best adapted to shallow water environments?
- e. Is acoustic imaging feasible in shallow water?

1.2 Organization of the Workshop

The Workshop participants listed in Appendix B were those who responded to a letter of invitation outlining the purpose, giving background material, and requesting an abstract for a 10-minute presentation addressing one or more aspects of the questions posed in the previous paragraph.

Three working groups were then established and the papers assigned among the three. The Working Groups were:

1. Environmental Acoustics and Modeling (R. Wagstaff, NORDA, Chairman)
2. Measurements and Survey Techniques (G. Lewis, NAVOCEANO, Chairman)
3. Classification Techniques (A. Eller, NRL, Chairman).

The papers are listed by title and author in Section 3. The presentations describing NORDA's present program (S. Stanic) and its additional proposed work (W. Kuperman and R. Wagstaff) were delivered as invited papers. The abstracts of all presented papers are also given in Section 3. After the presentations of the papers, the participants were asked to select a Working Group that best represented their interests. The Working Group constituents are shown in Appendix C.

1.3 Tabular Summary of the Proposed Program Plan of the Working Groups

1.3.1 Plans and Milestones for Characterization of the Bottom--Working Groups on Modeling and Surveys

| | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|--|--|--|-------------------------------------|---|
| Case 1 (Site 1) Homogeneous Bottom  | Theory Experiment design Site 1 survey | Experiment | Data analysis | Experiment (different season) | Data analysis assessment |
| Case 2 (Site 2) Weakly Nonstratified  | Theory | Theory Experiment design Site 2 survey | Experiment | Data analysis | Assessment of survey techniques |
| Case 3 (Site 3) Strongly Nonstratified  | --- | Theory | Theory Experiment design Site 3 survey | Experiment | Data analysis Assessment of survey techniques |

1.3.2 Plans and Milestones for Target Classification

Year 1: A. Planning; selection of targets; evaluation of target echo prediction
B. Time domain and reverberation modeling
C. Compute and measure free-field target response

Year 2: A. Signal processing studies--wave form, correlation, artificial intelligence
B. Continue time domain and reverberation modeling
C. Prediction of channel effects
D. Tank experiments

- Year 3:
 - A. Model simulations.
 - B. Fixed site experiments
 - C. Plan at-sea experiment

- Year 4:
 - A. Refine simulation models
 - B. At-sea experiment I

- Year 5:
 - A. At-sea experiment II
 - B. Data analysis
 - C. Assessment

2. WORKING GROUP PROPOSED PROGRAM PLANS

2.1. Environmental Acoustics and Modeling, R. Wagstaff (NORDA), Chairman

Focus: The Effects of the Bottom on Shallow Water Propagation

2.1.1 Introduction

In contrast to deep-water propagation, where purely waterborne paths predominate, in shallow water most paths interact many times with the bottom. Depending on the frequency, the energy may penetrate to great depths into the bottom. (For example, in some recent experiments with sonobuoys the 20 Hz component of diving waves has been observed to penetrate to depths of over 3 km into the sediment. This energy reemerges into the water column at a range of about 15 km from the source.) In view of the above, the characterization of subbottom features in terms of parameters, such as reflection coefficients, evaluated at the bottom interface will have to be reexamined.

In shallow water the bottom is usually characterized by a variety of sediment types and substructure. Layers are quite variable in thickness, slope, composition and cross section, all of which affect the acoustic properties. Bottom interaction models used in deep water studies often have not needed to take these variables into account. However, for shallow water, investigations are required that will lead to models incorporating these complexities.

Investigations of the influence of the bottom on acoustic propagation seem to be separable into two different classes of effects--deterministic and stochastic. The investigation of deterministic phenomena can lead to an understanding of the mean effects. This approach is usually responsible for laying the foundation of knowledge of the first order effects. Normally, it also provides the knowledge base from which the deficiencies in the deterministic approach are identified and establishes the need for considering stochastic processes to explain certain phenomena adequately. Descriptions of the stochastic processes, therefore, tend to lag the deterministic but are nonetheless important. It thus seems reasonable to separate the investigation of the phenomena into deterministic and stochastic.

The following is an outline of investigations that are important in constructing models of the bottom for studies of acoustic propagation in a shallow water environment. These investigations are both experimental and theoretical and are designed to provide successively more realistic descriptions of this complex problem.

2.1.2 Deterministic

I. *Laterally Homogeneous Models*

1. Existing propagation models should be interrogated specifically for shallow water propagation in order to determine sensitivity to the following acoustic parameters:

| | |
|--------------------------|--------------------|
| a. $v_p(z, \omega)$ | p-wave velocity |
| b. $\alpha_p(z, \omega)$ | p-wave attenuation |
| c. $v_s(z, \omega)$ | s-wave velocity |
| d. $\alpha_s(z, \omega)$ | s-wave attenuation |
| e. $\rho(z)$ | mass density |

In particular, these investigations should aim to establish conditions under which shear must be taken into account. This item is not anticipated to constitute a major task but the information is needed for subsequent work.

2. Results should be interpreted in terms of fundamental propagation concepts such as rays or modes. The purpose is to provide guidance for generalization to laterally inhomogeneous modeling.
3. Inverse techniques should be developed for determining the acoustic parameters specified in item I-1.

II. Laterally Inhomogeneous Models

Information gathered from studies under item I-1 forms the basis for generalization to models incorporating lateral inhomogeneity. Features to be incorporated in these models are as follows:

1. Sloping bottoms (two- and three-dimensional)
2. Layers with nonparallel boundaries (two- and three-dimensional)
3. Weak and strong inhomogeneities (two- and three-dimensional).

In addition, inverse techniques need to be developed to handle laterally inhomogeneous environments.

III. Experimental Data

Input to the above studies must be derived from field experiments designed to determine bottom characteristics. There appears to be a scarcity of data for roughly the first 500 m below the seafloor. New experimental methods including both acoustic and coring techniques should be developed to furnish this information.

IV. *Basic Research on Sediment Properties*

Recent data suggest that some of the acoustic parameters described in item I-1 are still not well defined. For example, very low values of compressional wave attenuation have been reported recently by a number of investigators. When these new observations are considered together with prior data, the spread in attenuation exceeds two orders of magnitude in the low frequency range (<1 kHz). In order to improve our understanding of overall sediment properties, the following studies are suggested:

1. Lab experiments designed to determine the intrinsic parameters, especially attenuation over a wide range of frequencies
2. Further development of theories that relate the macroproperties of sediment materials to their microstructure
3. Effects of scattering due to many thin layers
4. Effects of conversion to different wave types--an example would be Biot waves of the second kind.

2.1.3 Stochastic

I. *Objective*

This effort will provide estimates of the effect of statistical variations in the sea bottom on shallow water propagation and systems performance.

II. *Fundamental Points to be Addressed by a Stochastic Treatment of the Sea Bottom*

1. To determine the extent to which energy is scattered from the completely coherent ("deterministic") field and to identify the experimental and environmental parameters that control this scattering
2. To determine the impact of loss of coherence (space, time, frequency) at the receiver site
3. To estimate the importance of intensity fluctuations and correlations to system performance.

Stochastic models intended to address these objectives will be formulated in terms of second order (space, time, frequency) and fourth order statistics measured across a receiver array in the water column. The environmental input to the models will depend on the specific application.

Presently available models of a perfectly reflecting rough bottom require information on the rms height of the bottom variations and the characteristic length scales of these variations. Available models of a flat, penetrable sea bottom require information about attenuation, the rms fluctuations in density and sound speed, and the characteristic length scales of these variations.

III. Research Tasks to be Accomplished

1. Perform sensitivity studies on presently available computational codes in order to determine the impact of insufficient information about environmental parameters.
2. Develop extended second and fourth order theoretical statistical models that can incorporate additional or more refined statistics of the environment, an elastic bottom, etc.
3. Develop asymptotically or physically based models that can provide design estimates for limited ranges of system and environmental parameters.
4. Relate statistical models of coherent field propagation to phenomenological deterministic models.
5. Reduce available theoretical models to computational algorithms.
6. Develop models that can provide estimates of the effects of bottom variations on high resolution array algorithms.
7. Incorporate stochastic sea-bottom algorithms into available propagation and sea-surface codes in order to provide estimates for a realistic shallow water environment that includes a sound-speed profile and the possibility of multiple bounces.

IV. Experimental Support

Existing geophysical data will be examined in order to derive relevant bottom statistics. Further experimental measurements are needed for the assessment of the mean environmental properties and of the magnitude and scale lengths of dominant inhomogeneities in the bottom. Also, acoustic experiments must be made in order to validate the theoretical models. At a minimum, these will involve measurements of array performance or the degradation of various coherent processing or correlation techniques between sonobuoys.

V. Outputs

The output of this effort will be validated theories and computational capabilities needed to estimate the degradation of coherent processing techniques in terms of measurable bottom variations.

VI. Task Duration and Milestones

| Task | Research Option Year | | | | |
|---|----------------------|-----|-----|-----|-----|
| | 1st | 2nd | 3rd | 4th | 5th |
| <u>Modeling</u> | | | | | |
| 1. Environmental parameter sensitivity studies | | | | | |
| 2. New model development | | | | | |
| 3. Model complexity reduction tradeoffs | | | | | |
| 4. Relate coherent field-models to phenomenological models | | | | | |
| 5. Development of computational capability | | | | | |
| 6. Estimation of impact on high resolution arrays | | | | | |
| 7. Integration of sea bottom effects into more comprehensive propagation codes | | | | | |
| <u>Experiments</u> | | | | | |
| 1. Evaluation of existing shallow water geoacoustical data and identification of additional needs | | | | | |
| 2. Model validation experiments | | | | | |

2.2 Measurements and Survey Techniques,* M.G. Lewis (NAVOCEANO), Chairman

2.2.1 Background

In practically all attempts to compare observed shallow water acoustic features with existing model results, a major unknown to contend with is the influence of the bottom. In order to achieve agreement between measurements and derived results, some assumption is made concerning a bottom-related quantity.

The complexity of the measurement site, the funding limitations placed on the exercise, the objective of the particular exercise--all impact the nature, extent, and control over the exercise results, and making assumptions about the bottom may be the only option one has. As a result, assertions and conclusions are made that may be correct in part or limited in application to the point where accurate prediction of performance is rarely achieved and, if so, may be only coincidence.

The aim of this program is to improve the accuracy of prediction from both deterministic and stochastic standpoints by developing a fuller understanding of the influences of the shallow water environment on propagation, noise, and scattering. It is recognized that surface interactions and properties of the water medium interplay with effects of the bottom in determining acoustic characteristics of a particular region. To pursue this aim in a consistent, systematic manner within budget constraints, the initial approach of the program will be to achieve a fuller understanding of the influence of bottom-related quantities on the acoustics of shallow water.

2.2 Purpose

Our purpose in this program is to determine and obtain the fundamental geologic, geophysical and oceanographic data required to provide fuller understanding of the influence of the bottom roughness, bottom-water interface, and bottom substructure on the propagation of sound and its coherence in shallow water. The frequency regime emphasized will address the ASW sonar frequencies for both passive and active systems and as such will have a nominal upper limit of 5 kHz.

*See Appendix D for Minority Report by J.J. Hanrahan (NUSC, New London).

2.2.3 Approach

The quantities to be measured will be those deemed to affect significantly the Navy's ability to predict performance within desired accuracy. These quantities will be identified with the aid of deterministic and stochastic theory and empirical relations. Effective ways of measuring these quantities will be determined and, if required, instrumentation for accurately measuring these quantities will be developed. Additionally, a test-bed concept will be developed whereby several examples of bottom types will be identified for intensive, systematic measurements of both acoustic signals and bottom-related quantities to establish or confirm predictably accurate relationships.

Some of the significant acoustic quantities to be measured in the test-bed areas are velocity of propagation for both compressional and shear waves, reflection coefficient and its spatial correlation, sound speed field in the water mass, and weak scatter. Some of the bottom-related quantities to be measured are roughness, density distribution, bathymetry, layer thickness, and rigidity-related parameters.

2.2.4 Measurement and Survey Technique Issues

- (1) Investigate the applicability of deterministic and statistical modeling approaches to address the question of spatial and temporal variability of physical parameters in the complex shallow water environment.
- (2) Determine the precision with which relevant environmental parameters of given areas can be characterized using existing data and/or proposed environmental measurements.
- (3) Establish the adequacy of these characterizations for input to basic acoustic oceanographic models and define the geographic scales.
- (4) What survey/measurement techniques can be used to obtain these properties and how can they be validated.

2.2.5 Survey Objective

The general objective is to construct a measurement program that will characterize one or more circular areas of about 30-km diameter in terms of physical, both geological and oceanic, properties appropriate for explaining acoustic propagation in the frequency range from 10 to 5000 Hz and provide acoustic propagation data in sufficient detail and completeness to enable the test of state-of-the-art environmental acoustic models. The first area is to be selected such as to minimize horizontal changes over the entire area. Subsequent areas are to be selected in order to introduce varying degrees of horizontal change.

The specific form of the characterization of the areas will include

- (a) Geological provinces
- (b) Physical properties (from cores and in-situ measurements)
- (c) Geoacoustic properties (compressional and shear attenuation coefficients)
- (d) Complex reflection coefficient as a function of horizontal wave number and frequency (mean and fluctuation)
- (e) Vertical and horizontal coherence lengths for use in array applications
- (f) Bathymetry
- (g) Investigation of effectiveness of geophones versus hydrophones as acoustic sensors
- (h) Complex elastic moduli.

2.2.5.1 Experimental Procedures

Determination of the survey-objective measurement quantities will be achieved by the following methods:

- (a) Use diving wave measurements of p-wave attenuation with sonobuoys
- (b) Obtain a number of cores to good depth--measure p , N , permeability
- (c) Determine complex shear and bulk modulus, grain-size distribution, lithology
- (d) Measure rigidity models and v_s in situ using interface (Stonely) waves, shear waves, transient vibrations, gravity waves
- (e) Measure propagation characteristics as a function of source and sensor depth and as a function of range, azimuth, and frequency using a broadband source
- (f) Use arrays of different sensor types (to measure pressure and particle velocity motion) with both broadband and narrowband sources
- (g) Make broadband and narrowband measurements of complex reflectivity and horizontal and vertical spatial coherence along parallel lines on different azimuths.

2.2.6 Experimental Program

Year 1 a. Planning, experiment design, and initial site survey of Case (1), horizontally stratified area

 b. Theory for Case (2), weakly nonstratified area

 c. Study effort on how to make needed measurements for cases (1), (2), and (3). Case (3) is a strongly nonstratified area.

 d. Survey Site (1)

Year 2 a. Experiment, Site (1)

 b. Theory, Site (2)

 c. Planning of experiment for Site (2)

 d. Survey Site (2)

Year 3 a. Data Analysis, Site (1)

 b. Experiment, Site (2)

 c. Theory, Site (3)

 d. Survey Site (3)

Year 4 a. Data Analysis, Site (2)

 b. Experiment, Site (3)

 c. Revisit Site (1)

Year 5 a. Data Analysis, Site (3)

 b. Report

2.2.7 Products

- (1) Acoustic characterization of three shallow water types
- (2) Evaluations of important parameters for input to acoustic models
- (3) Identification of useful survey techniques in shallow water areas
- (4) Recommendations for extrapolation of results to similar geologic areas
- (5) Notes on seasonal variation
- (6) Concept formulation of shallow water data bank.

2.3 Classification Techniques,* A.I. Eller (NRL), Chairman

2.3.1 Background

Concern that Navy operational capability in shallow water may not be keeping pace with corresponding capabilities in deep water, and corresponding concern that techniques to detect and classify quiet, low-Doppler targets in shallow water are not being adequately addressed by current basic research programs, provide the background motivation for this portion of the proposed shallow water acoustics research program.

Previous shallow water acoustics research has emphasized individual programs in propagation, noise, and reverberation. The understanding gained from these investigations, while not complete, has matured sufficiently that we may begin the next logical step, namely the examination of target detection, classification, and localization in shallow water environments.

From past research it is generally recognized that the shallow water acoustic environment is an especially complex environment. Environmental features that challenge attempts to detect and classify targets are propagation effects such as multipath structure and dispersion, a greater variability of environmental parameters, and the severe background clutter resulting from high densities of local shipping and, for active sonar, high densities of bottom and volume scatterers. The classification problem in shallow water is compounded by the wide range of Navy systems that must operate in this environment. The thrust of the proposed research is to find ways that exploit the complexity of the environment in order to provide the maximum amount of information on which to base classification decisions.

*See Appendix E for Detailed Working Group Report.

2.3.2 Purpose

The objective of the proposed classification research program is to identify characteristics of targets and of the shallow water acoustic channel that can be exploited to provide substantially improved classification capabilities. The payoff will be the establishment of performance bounds for a classification approach. Program goals are to provide realizable procedures by which desired targets can be discriminated from all other contacts.

2.3.3 Approach

The technical approach to be followed involves the identification of target features that can be used to distinguish false targets, the prediction and measurement of how these features are modified when propagated through the acoustic channel, and the prediction and measurement of target content different from noise and reverberation. Specific target parameters that will be considered include speed, location (range and angle), depth, orientation, orientation, size, and structure (complexity and curvature).

The research approach is based on the premise that the extreme complexity of received acoustic signals in shallow water contains extensive information about both the target and the environment and offers unique opportunities to use the environment as a source of classification clues. The fundamental hypothesis is that the environment in the field can be utilized to advantage in the development of an environmental acoustic prediction capability. This will be done by using adaptive signal processing. The individual steps will be to: (1) receive signals with corresponding target parameters and then to estimate target state using a decision-making approach to estimate target state.

Specific tasks in the research program outline include a planning and analysis task, a modeling task, and a measurement task. The general flow of events is to work toward a major experiment occurring in two phases. The first phase is in the second half of year 3, and the second phase is in the first half of year 4.

In the first year, a set of candidate targets will be selected, and features of the targets that serve as possible recognition clues will be identified. Target responses to known acoustic signals will be measured under free-field conditions, and corresponding calculations will be made of target response. Comparison of predicted and measured responses will provide a calibration at this time of the adequacy of existing target response models. Also during the first year, modeling of the time domain response and of reverberation in the acoustic channel will be started.

In the second year, time domain response and reverberation modeling will be continued. An experiment will be conducted in which target echo waveforms are transmitted in one direction in order to measure the changes induced by the acoustic channel. Reverberation response of the transmitted waveforms will be measured also. Both target echo and reverberation results will be compared to corresponding predictions. Results of the comparison will provide a check on the adequacy of time domain and reverberation models. Also during the second year, a simulation model capability will be started.

In the third year, the simulation model will be used to simulate the planned experiments. Seagoing equipment will be tested, and the first phase of the classification experiment will be conducted. In this experiment several targets will be used, with varying speeds and depths. The experiment will test whether the selected waveforms, signal processing, and prediction models are adequate to promote an improved capability to distinguish the targets.

In the fourth year, the second phase of the experiment will be conducted, and data from both phases will be analyzed.

In the fifth year, the remaining analysis will be conducted, and the results of the program will be assessed.

Attention will be paid to planning and to extending the concept of the program. This will allow new ideas to be brought into the program along the way.

2.3.4 Program Plan

Year 1

- a. Planning; selection of targets; identification of currently available, relevant data; evaluation of target echo prediction capability.
- b. Begin time domain and reverberation modeling.
Compute free-field target response.
- c. Measure free-field target response.

Year 2

- a. Planning; evaluation of artificial intelligence (AI) concepts. Evaluate status of signal waveform modeling and ability to do replica correlation.
- b. Continue time domain and reverberation modeling. Predict reverberation for candidate waveforms and receiving apertures. Predict channel effects on echo signal form. Begin simulation modeling.
- c. Conduct experiment at fixed test range. Conduct relevant tank experiments. Begin hardware procurements.

Year 3

- a. Planning; data analysis.
- b. Conduct model simulations of intended experiments.
- c. Sea trial of equipment, Phase I experiment. Conduct relevant tank experiments. Hardware reengineering.

Year 4

- a. Data analysis.
- b. Refine simulation modeling.
- c. Conduct Phase II of experiment.

Year 5

- a. Data analysis and program assessment.

3. ABSTRACTS OF PRESENTATIONS

3.1 List of Presentations

NORDA High Frequency Shallow Water Acoustics Program--S. Stanic

S. Stanic, M. Richardson, and P. Fleischer -- "Effects of Shallow Water Geological Processes on High Frequency Acoustic Scattering"

Environmental Acoustics and Modeling--R. Wagstaff, Chairman

W. Kuperman and R. Wagstaff -- "Overview and NORDA Proposal"

T. Yamamoto -- "Criteria for Biot Bottom Models for Acoustic Normal Mode Analysis"

R. Dicus -- "Proposed Numerical Tools of Performance Prediction for Arrays in the Vicinity of Rough, Laterally Variable Bottoms"

J. McCoy -- "Extended Parabolic Wave Theories for Incorporating the Ocean Bottom"

R. Stoll -- "Attenuation of Bottom-Interacting Acoustic Waves"

R. Stoll -- "Factors Affecting an Acoustical Model of the Bottom"

D. Jackson -- "Physical Models for High Frequency Bottom Scattering"

S. McDaniel and J. Beebe -- "Mean Grain Size as a Descriptor of Sediment Properties"

D. Gordon -- "Problems Arising in Normal Mode Analysis in Shallow Water"

D. Stickler -- "Continuous Modal Contributions"

L. Felsen and J. Arnold -- "Rays, Ray Spectra and Intrinsic Modes for a Range-Dependent Shallow Ocean"

E. McLeroy -- "Significance of Horizontal and Vertical Variation in Environmental Parameters to Shallow Water Propagation"

Measurements and Survey Techniques--G. Lewis, Chairman

G. Lewis -- Introductory Remarks

C. McKinney -- "Shallow Water Acoustics and Mine Warfare"

D. Jackson -- "Acoustic Surveys for Torpedo Guidance and Control Applications"

T. Davis -- "Survey Design"

G. Frisk and J. Lynch -- "Shallow Water Waveguide Using Hankel Functions"

D. Stickler -- "Inverse Scattering for Ocean Bottom Sediments"

H. DeFerrari, H. Nguyen, and N. Williams -- "Shallow Water Transmission Fluctuations--Ongoing Experiments"

R. Houtz -- "Long Array Seismic Experiment--Diving Wave Results"

S. McConnell -- "Correlation of Sonar and Radar Backscatter from the Sea Surface"

E. Thorsos -- "Bubble Distributions for High Frequency Surface Scattering"

J. Beebe -- "Shallow Water Dispersion Analysis as a Tool for Determining Seabed Parameters"

R. Jennette -- "Low Frequency Transmission Loss in Chesapeake Bay"

A. Sykes -- "Project MIMI Revisited"

K. MacKenzie -- "Long-Range Shallow-Water Reverberation"

J. Posey -- "Short Term Coherence in High Frequency Propagation"

G. Sutton and T. Brocher -- "Bottom Motion and Pressure of Low Frequency Signals and Noise on a Continental Shelf"

Classification Techniques--A. Eller, Chairman

A. Eller -- "Overview of Classification Techniques"

A. Eller -- "Azimuthal Resolution"

C. Katz -- "A Concept for Target Depth Estimation"

E. Pipkin -- "Vertical Processing Sonar"

L. Flax -- "Low ka and Resonance Study of Targets"

S. Numrich, H. Dale, and L. Dragonette -- "Acoustic Identification of Underwater Targets"

L. Felsen and E. Heyman -- "Wavefront Echoes and Complex Resonances for Target Identification"

C. Eggen -- "Classification Using Human-Like Reasoning"

G. Garrison -- "Arctic Shallow Water Problems"

W. Roderick and B. Cole -- "Shallow Water Reverberation-Limited Conditions and Active Sonar Waveform Design"

NORDA High Frequency Shallow Water Acoustics Program

EFFECTS OF SHALLOW WATER GEOLOGICAL
PROCESSES ON HIGH FREQUENCY ACOUSTIC SCATTERING

S. Stanic, M. Richardson, and P. Fleischer
Naval Ocean Research & Development Activity

NORDA's 6.1 high frequency program will develop a fundamental understanding of the physics of high frequency shallow water bottom scattering. Simultaneous acoustic and environmental measurements will be used to identify and isolate different bottom scattering mechanisms and to resolve their effects on acoustic signals. Data from these measurements will be used to verify or modify current acoustic and geoacoustic models and develop new models.

Experimental sites will be selected on the basis of data provided by side scan sonar imagery, sediment cores, and stereo photography. The results will be used to evaluate the relationships among different bottom types and establish the predictability of various bottom parameters. Oceanographic measurements will be used to detail the ocean thermal finestructure, water column and near bottom currents, and water column sound velocity profiles.

The acoustic experiments will utilize a series of nonlinear sources, broadband hydrophones, and bottom mounted stable platforms to measure the bottom forward and backscattered signal levels. These experiments will also provide estimates of the scattered signal's spatial coherence. The acoustic measurements will be made as a function of frequency (5 kHz to 200 kHz), pulse length (200 μ s to 10 ms) and grazing angle (5° to 20°).

5.2. Environmental Acoustics and Modeling

OVERVIEW AND NORDA PROPOSAL

W. Kuperman and R. Wagstaff
Naval Ocean Research & Development Activity

The physics of sound propagation in the ocean and, in particular, shallow water is reviewed. The most widely used propagation models (ray, mode, fast field, parabolic equation) are presented and their areas of applicability are indicated. New PE methods have been developed that efficiently and accurately account for strong bottom interaction. A few numerical examples are included to show the consistency among the different computer models in overlapping regimes of validity. The ability of the acoustic models to describe sound propagation accurately in complicated ocean environments is demonstrated through a sequence of model/data comparisons. When sensing objects in the ocean acoustically, detection is often limited by ambient noise which comes from the sea surface and ships. Noise modeling is discussed briefly in relation to array processing techniques. The NORDA proposal for low frequency geoacoustic studies in shallow water is then presented.

CRITERIA FOR BIOT BOTTOM MODELS FOR ACOUSTIC NORMAL MODE ANALYSIS

T. Yamamoto
Ocean Engineering Division
Rosenstiel School of Marine and Atmospheric Science
University of Miami

In conjunction with the acoustic normal mode analysis, general validity criteria for the commonly used Biot fluid bottom models and the Biot elastic bottom models are developed by comparisons of these models with the poro-elastic bottom model in which the Biot theory is used in an exact manner. Two universal bottom parameters are found to be the poro-viscous frequency number κ and the relative shear velocity (V_s/c). General error diagrams for determining the errors associated with the fluid bottom models and the elastic bottom models are constructed for the entire ranges of the sediment properties and wave frequency. It is found that the fluid models are applicable only to fine soft sands. The elastic bottom models are applicable to most sediment bottoms except coarse sands and permeable rocks. For the bottoms made of coarse sands and permeable rocks, only the Biot poro-elastic bottom modes are valid.

PROPOSED NUMERICAL TOOLS OF PERFORMANCE PREDICTION FOR ARRAYS
IN THE VICINITY OF ROUGH, LATERALLY VARIABLE BOTTOMS

R. Dicus
Naval Research Laboratory

A 3-dimensional, parabolic-equation (3DPE), split-step algorithm developed at the Naval Research Laboratory is proposed for study of bottom coherence degradation effects. The algorithm will permit lateral variation in bathymetry and bottom sound speed. The 3DPE may be exercised in Monte-Carlo fashion to model coherence-degradation effects in the near field of the bottom and to provide a baseline for proposed stochastic theories. A proposed stochastic model would incorporate a bottom-coherence transfer function into a coherence-propagation algorithm. Inverse techniques based on the same formalism would provide a second-moment description of the bottom from array measurements.

EXTENDED PARABOLIC WAVE THEORIES FOR INCORPORATING
THE OCEAN BOTTOM

J. McCoy
The Catholic University of America

Research programs at Catholic University that highlight the extensions referred to in the title are outlined. Emphasized will be an uncertainty in the correct form of a parabolic theory that incorporates a distortion mode, as well as a pressure mode, required when propagating in linearly elastic solids. Further, in considering scalar wave theory, a framework (based on an exact factorization of the Helmholtz equation for range independent environments) is presented for deriving a hierarchy of extended parabolic theories, each extended theory removing one or more of the accepted restrictions on the ordinary theory.

ATTENUATION OF BOTTOM-INTERACTING ACOUSTIC WAVES

R. Stoll
Lamont-Doherty Geological Observatory

New data from measurements of attenuation in situ include some values much lower than those previously reported in the range of 10 to 250 Hz. The resulting wide range of values in this frequency range suggests that the overall attenuation may be strongly influenced by the small scale structure of the sediments. As a result of this structure, interbed multiples, conversion of wave type, and other mechanisms which tend to produce an apparent attenuation come into play. Since conventional methods of acoustic exploration do not resolve the small scale structure in this frequency range, new methods are required. Moreover, the wide spread introduced by the new data suggests that it is not appropriate to estimate attenuation by extrapolation from a higher frequency range.

FACTORS AFFECTING AN ACOUSTICAL MODEL OF THE BOTTOM

R. Stoll
Lamont-Doherty Geological Observatory

New studies of both unconsolidated sediment and rock have yielded a better understanding of various factors that influence wave velocity and attenuation. Several of these factors are often overlooked or neglected in both field and laboratory studies. Two, in particular, which are very important are the static intergranular stress and the dynamic strain amplitude. The intergranular stress plays a strong role in determining the dynamic shear modulus both in laboratory experiments and in near-bottom sediments that are not lithified. Many simple experiments do not allow measurement or control of the static stress field and so are inconclusive in defining acoustic properties. The dynamic strain amplitude affects the sediment properties in a nonlinear manner until strains are smaller than about 10^{-6} . Since most bottom interacting waves will occur at strains below this level, laboratory measurements must be made in the linear range.

PHYSICAL MODELS FOR HIGH FREQUENCY BOTTOM SCATTERING

D. Jackson
Applied Physics Laboratory, University of Washington

The mechanisms that govern high frequency bottom scattering are poorly understood. Sediment grain size is an inadequate bottom descriptor, as sites with similar grain size differ in backscattering strength by as much as 15 dB. Recent experiments in Puget Sound and the North Sea (D.R. Jackson et al., to be presented at ASA meeting, May 1983) indicate that roughness dominates the scattering process at shallow and steep grazing angles, while sediment inhomogeneity dominates over the middle range of angles. Bioturbation has a strong influence on high frequency bottom interaction and may cause strong spatial variability in scattering strength. In studying spatial variability, real-time survey measurements of scattering strength are needed with detailed in-situ measurement of sediment properties at acoustically interesting sites. High-resolution bottom roughness spectra show power-law behavior with a slow falloff that causes predictions of the composite roughness model to become unduly sensitive to the choice of a cutoff parameter. Progress has been made recently in incorporating multiple roughness scales through modification of the Kirchhoff approximation and by exploiting the fractal nature of the interface. Further development of such models is required, including detailed comparison with experimental data.

MEAN GRAIN SIZE AS A DESCRIPTOR OF SEDIMENT PROPERTIES

S. McDaniel and J. Beebe
Applied Research Laboratory, The Pennsylvania State University

Acoustic transmission loss in shallow water is strongly dependent on the acoustic properties of the seabed. To predict these properties, a semiempirical model based on the Biot theory is developed that requires only a single sediment description, mean grain size. Sediment characteristics derived using this theory are incorporated in a normal-mode model to predict transmission losses that compare favorably with experimental results.

PROBLEMS ARISING IN NORMAL MODE ANALYSIS IN SHALLOW WATER

D. Gordon
Naval Ocean Systems Center

Many important aspects of shallow water propagation can be determined by modeling sound speed, sound absorption, and density. Normal mode methods accomplish this but not without some difficulty. This paper demonstrates normal mode products including plots of dispersion, mode attenuation, group velocity, and reflection coefficients. Some aspects of the plots can be explained by ray theory and simple reflection coefficients. However, diffraction, boundary effects, and multiple ducts require wave theory. Ducts exist in the sediment as well as the water and increase the complexity of the mode structure. This increases the difficulty of locating modes.

CONTINUOUS MODAL CONTRIBUTIONS

D. Stickler
Courant Institute of Mathematical Sciences

In shallow water, the continuous spectrum can be important; in fact, for sufficiently low frequencies it can be the only component of the pressure field. In a 1974 paper Stickler showed some numerical examples to illustrate the importance of the continuous spectrum. The technique used to make those calculations could be quite expensive. In a recent paper Stickler and Ammicht developed for the Pekeris model an asymptotic technique for describing the contribution of the continuous spectrum. This method is discussed.

RAYS, RAY SPECTRA AND INTRINSIC MODES FOR A
RANGE-DEPENDENT SHALLOW OCEAN

L. Felsen

Dept. of Elect. Eng. and Computer Science/Microwave Research Institute
Polytechnic Institute of New York

J. Arnold

Dept. of Electric and Electronic Engineering
University of Nottingham

Ray acoustics is an effective method for analyzing propagation in fairly general ocean environments. In a shallow ocean with weak dependence on range, many multiple ray fields may contribute to a distant observer. Moreover, ray acoustics runs into difficulties at caustics, critical incidence and shadow boundaries. Adiabatic mode theory provides an alternative description but is inadequate to track conversion from the trapped to the radiating regime when the guiding environment incorporates mode cutoff, as for upslope propagation. The interposition of ray spectra that smear multiple reflected ray fields out into intrinsic modes, which accommodate the cutoff transition, furnishes a promising approach that overcomes the difficulties at both ends. Application of the method to a wedge-shaped ocean above a penetrable bottom is demonstrated and its extension to other configurations discussed. Also included are hybrid ray-mode formulations for the incident signal and for signals scattered by a target in the ocean duct.

SIGNIFICANCE OF HORIZONTAL AND VERTICAL VARIATION IN
ENVIRONMENTAL PARAMETERS TO SHALLOW WATER PROPAGATION

E. McLeroy

Naval Coastal Systems Center

Empirical evidence is presented to support the view that many sea floor parameters must be considered in understanding shallow water propagation and that both horizontal and vertical variations in these parameters are significant in even a limited operational area. This evidence is derived from a rather extensive set of environmental and acoustic/seismic propagation measurements made on a limited portion of the northern Gulf slope and shelf.

5.3 Measurements and Survey Techniques

INTRODUCTORY REMARKS

G. Lewis
U.S. Naval Oceanographic Office

NAVOCEANO conducts survey operations worldwide in support of the U.S. Navy operating fleets. We define shallow water, for purposes of supporting these Naval fleets, as:

- a. Water depths ranging from 20 m to 1000 m
- b. Where acoustic propagation is dominated by boundary interaction and is reverberant and the water column is complicated by extreme oceanographic variability, both temporally and spatially.

Requirements for such data are received not only from fleet commands but from the system development community as well. Fleet requirements fall into two main categories: tactical utilization doctrine, and system performance prediction. The system development community tends to revolve about hardware design and various use scenarios for the operational environment and quickly separates into various factions responsible for the timely introduction of capabilities to the Naval fleets, to wit, ASW systems, torpedo systems and mine warfare and mine countermeasure systems. In the latter case, the key issue underlying these requirements is how to use the Navy's research and development dollars with the oceanographic survey resources for the best return on investment, i.e., sampling strategy or survey design.

Survey issues were summarized in three major groupings:

- a. Characterize the environmental parameters of: sound speed profile, air/sea interaction, surface-wave properties, bathymetry, bottom and sub-bottom geoacoustic characteristics, biological and man-made noise and volume scattering properties.
- b. Determine the precision with which relevant environmental parameters of given areas can be characterized using existing data and/or proposed environmental measurements.
- c. Establish the adequacy of these characterizations for input to basic acoustic and oceanographic models and determine the required geographic scales.

SHALLOW WATER ACOUSTICS AND MINE WARFARE

C. McKinney

Applied Research Laboratories, The University of Texas at Austin

There are at least three aspects of mine warfare that involve shallow water acoustics. For shallow water mines and acoustic mine-sweeping, the acoustic characteristics of the bottom and surface are of importance. For minehunting with sonars, target classification is a major problem. In this respect, high resolution in angle and range for target and shadow imaging are popular. In addition, bottom reverberation is an important factor for which a good model for bottom backscattering is important.

ACOUSTIC SURVEYS FOR TORPEDO GUIDANCE AND CONTROL APPLICATIONS

D. Jackson

Applied Physics Laboratory, University of Washington

Several survey-type experiments have been staged in the past 15 years with the torpedo guidance and control application as the driving force. These experiments have generally been designed to characterize false targets and/or reverberation levels. In the mid-1970's, NOSC collaborated with the Southwest Fisheries Center in a series of cruises under the BIAS program. This work resulted in a large data set on biological false targets in the California Current. During the technical assessment phase of the Advanced Lightweight Torpedo Project, cruises were undertaken by NOSC and APL-UW to gather false target data in the Mediterranean, Northeast Pacific, Caribbean, and North Atlantic. These data sets are not as extensive as the California Current data, but data on cetaceans were obtained in the Mediterranean and split-beam data were obtained on biological and bottom features in the other areas. As part of the TAEAS program, a survey of the Quinault Range was performed in 1980. This survey provided data on biological targets and bottom backscattering strength. Recently, a NAVOCEANO survey operation was conducted in the Gulf of Mexico, including measurements of false targets and surface, bottom, and volume reverberation. This experiment is an important step toward the development of a much-needed high frequency survey capability.

SURVEY DESIGN

T. Davis
U.S. Naval Oceanographic Office

The relationship between survey design and the other main elements of the environmental/operational complex is presented. The theory utilized for designing two-dimensional surveys of oceanographic or geophysical parameters is based on a model of the survey process which consists of parallel delta function ridges and their representation in the two-dimensional frequency domain. The resulting convolution process between the spectral model of the environmental parameter and the spectral model of the sampling process results in a capability for estimating the spectrum of the sampling error. Integrating this error spectrum yields a set of survey design decision aids consisting of error variance as a function of track spacing, track direction, if appropriate, and down track sampling rate. An example of this process is applied to design an oceanographic sound speed survey in both time and space in order to produce a digital model of the environment to a specified accuracy stated in terms of mean square sampling error.

SHALLOW WATER WAVEGUIDE USING HANKEL FUNCTIONS

G. Frisk and J. Lynch
Woods Hole Oceanographic Institution

A coherent processing technique is proposed for the characterization of shallow water channels. For a horizontally stratified ocean and bottom, the method consists of measuring the magnitude and phase versus range of the pressure due to a cw point source and Hankel transforming this data to obtain the depth-dependent Green's function versus horizontal wavenumber. The Green's function contains all the information about the channel necessary to solve the forward problem, including the nature of the discrete and continuous spectra and the plane-wave reflection coefficient of the bottom. Characteristics of the Green's function can also be used to infer acoustic properties of the bottom. Results for simple examples are presented using synthetic data and implications for the nonstratified case are discussed.

INVERSE SCATTERING FOR OCEAN BOTTOM SEDIMENTS

D. Stickler
Courant Institute of Mathematical Sciences

In shallow water, the role of the bottom can be quite significant and therefore methods to determine the acoustic parameters of the bottom are quite important. Trace formula methods initially derived by P. Deift and E. Trubowitz can be exploited to determine the complex sound speed and density profiles. A discussion of this method describing some of its features as well as numerical examples illustrating its accuracy is given.

SHALLOW WATER TRANSMISSION FLUCTUATIONS--ONGOING EXPERIMENTS

H. DeFerrari, H. Nguyen, and N. Williams
Rosenstiel School of Marine and Atmospheric Science
University of Miami

Transmission through the deep ocean by refracted paths is characterized by remarkable stability making possible coherent processing, large aperture arrays and acoustic remote sensing of oceanographic variability. Shallow water fluctuations are not well understood nor as thoroughly measured. We have begun an experimental program in the Florida Straits to measure temporal variability of pulse-like broadband transmission. The experiments use various geometries with moored sources and receivers. Initial results suggest shallow water transmission by multiple bottom bounces exhibits far more incoherence and pulse spreading than deep ocean transmission. Data and model results will be discussed and also plans for future experiments.

LONG ARRAY SEISMIC EXPERIMENT--DIVING WAVE RESULTS

R. Houtz
Gulf Research

Two-ship synthetic apertures were obtained from the Long Array Seismic Experiment (LASE). Effective array lengths of 10 km were achieved every 50 m, and hence a digitally recorded "sonobuoy" can be synthesized every 50 m. One hundred and twenty-four gathers were used to invert travel-time plots of diving wave arrivals. Velocity contours were computed on the resulting 6000 velocity-depth points. Data analysis shows that velocity gradients decrease uniformly seaward across the shelf. Comparisons with sonic logs from wells and with interval velocities computed from semblance picks reveal that diving wave velocities may be 4% to 5% faster than vertically oriented measurements. Slight inaccuracies are therefore inherent when multiple bounce paths with diving wave turnarounds are modeled from vertical measurements.

CORRELATION OF SONAR AND RADAR BACKSCATTER FROM THE SEA SURFACE

S. McConnell
Applied Physics Laboratory, University of Washington

Recent work¹ which examined the applicability of the composite roughness model to acoustic and radar backscatter from the sea surface in three wavelength bands showed a strong connection between the two, particularly at longer wavelengths and higher grazing angles. Comparisons of data taken in the open ocean with the model predictions showed that there were differences in the level and grazing angle dependence between the measured acoustic and radar backscatter levels at short wavelengths ($\gtrsim 10$ cm), but that both acoustic and radar backscatter levels depended on wind speed (acoustic scattering from near surface bubbles was suggested as the reason for the differences). As a basis for developing radar remote sensing techniques it is proposed that this work be extended to shallow water conditions and to a direct intercomparison between radar and sonar backscatter where, if possible, the same sea surface patch is simultaneously irradiated/sonified. In addition to developing remote sensing techniques this work should also help delineate the roles of surface waves (small as well as large scale), wave breaking, spray, and bubbles in the scattering process.

A radar/sonar intercomparison is especially important in shallow water where strong variations in the spatial distribution of backscatter levels can occur because of modifications in the air-sea interaction processes due to variations in fetch and water depth. Thus, the eventual development of radar survey techniques (using SASS, for example, combined with MAD and laser surveys) useful for predicting sonar sea surface scattering characteristics becomes quite relevant in shallow water, where reconnaissance by airplane-mounted radars can provide rapid coverage of the spatial variations and can give in-situ results which may not be available from surface vessels or submarines.

¹S.T. McDaniel and A.D. Gorman, "Acoustic and Radar Sea Surface Backscatter," J. Geophys. Res. 87, 4127-4136 (1982).

BUBBLE DISTRIBUTIONS FOR HIGH FREQUENCY SURFACE SCATTERING

E. Thorsos
Applied Physics Laboratory, University of Washington

The relative importance of surface waves and of near surface bubbles as they affect shallow water propagation and reverberation at high frequencies needs to be further clarified. Near surface bubbles can cause significant energy absorption and scattering at high frequencies, an effect that has been observed and must be included in surface scattering models. A necessary model input is the near surface bubble distribution, which originates from wave action and biological processes. To provide a method of reliable bubble measurement near the sea surface (and to develop a potential acoustic survey technique), it is proposed that acoustic backscatter measurements of bubble distributions be carefully compared with direct photographic measurements made simultaneously. Bubble measurements at sea should be undertaken with the goal of providing a model of wave generated bubble distributions as a function of surface conditions. Similar measurements should also be made in shallow water areas where biologically produced bubbles are thought to be important.

SHALLOW WATER DISPERSION ANALYSIS AS A TOOL FOR DETERMINING SEABED PARAMETERS

J. Beebe
Applied Research Laboratory, The Pennsylvania State University

While dispersion analysis has been around since Worzel, Ewing and Pekeris [Geol. Soc. of Am., Memoir 27 (1948)] pioneered its use in the 1940's, it has received relatively little attention as a technique for determining the environmental parameters necessary to describe shallow-water propagation. When used in conjunction with a normal-mode propagation model, this type of analysis provides a sensitive technique for determining the geoacoustic parameters of the upper sedimentary layers. The technique is described for various bottom structures and results are presented for a sandy bottom. Suggestions for improving the technique will be discussed.

LOW FREQUENCY TRANSMISSION LOSS IN CHESAPEAKE BAY

R. Jennette
Physics Department, U.S. Naval Academy

As part of a Merchant Vessel Source Level Measurement Program, transmission loss has been obtained in the Chesapeake Bay shipping channel. Fifteen tones (every 1/3 octave from 20 Hz to 500 Hz) were transmitted and analyzed. Source/receiver separations varied continuously from 300 yd to 1500 yd, and are accurately known. For each of the tones above the cut-off frequency, the resulting transmission loss shows the expected interference patterns superimposed on a (roughly) 15 log r envelope.

PROJECT MIMI REVISITED

A. Sykes

During the 1960's, Acoustic Programs of the Office of Naval Research sponsored an environmental acoustical study in the Straits of Florida--PROJECT MIMI (University of Miami/University of Michigan)--to determine how factors in the oceanic/atmospheric environments influence sound propagation. Water column variability resulting from a number of physical mechanisms was found to have significant, and occasionally even dramatic, effects. This paper will present a few of the MIMI results, and try to place them in a perspective suitable for consideration at a 1983 Shallow Water Workshop.

LONG-RANGE SHALLOW-WATER REVERBERATION

K. Mackenzie

Long-range shallow-water reverberation measurements were obtained to ranges of 80 km at 350, 700, and 1200 Hz over an extensive shelf of flat sand southwest of San Francisco, California. Bottom properties were surveyed previously for optimum test design. Data were collected at depths of 100 to 125 m over areas where the sonoprobe indicated a sediment thickness greater than 11 m. The source and receiver were mounted on a submerged submarine, USS BAYA, which was stationed motionless in the water column. The horizontal receiving array consisted of 40 equally spaced hydrophones on a boom. Five beams were formed, each of 3.8° width at 700 Hz and 2.2° at 1200 Hz. The sound speed profiles were essentially isothermal because the water had been thoroughly mixed by a heavy 4-day storm just before the operations. Reverberation data with 250 ms pulses were reduced every 0.01 s and 10 successive pings were averaged. Reverberation levels were computed by a simple energy flux density model (J. Acoust. Soc. Am. 34, 62-66, 1962). Mean values and computed reverberation levels are in excellent agreement. No other comparable data exist.

SHORT TERM COHERENCE IN HIGH FREQUENCY PROPAGATION

J. Posey
Naval Ocean Research & Development Activity

Imaging techniques that involve coherent processing are impaired by medium randomness which degrades coherence. A thermal microstructure measurement system (TMMS) for shallow water deployment has been fabricated and tested. The TMMS is a high speed, fixed location system with 12 thermistors at spacings from 2 cm to 2 m. The TMMS data can be used with the Wenzel saturation theory to predict loss of temporal coherence in high frequency signals. In a parallel laboratory study, the Wenzel theory has been verified for the transition region. In this model study, thermal randomness is produced in a large water tank by heating near the bottom or cooling near the surface.

BOTTOM MOTION AND PRESSURE OF LOW FREQUENCY SIGNALS AND NOISE ON A CONTINENTAL SHELF

G. Sutton
Rondout Associates, Incorporated

T. Brocher
Hawaii Institute of Geophysics

A line of three bottom seismographs (three components plus hydrophone) spaced about 18 km apart at depths of 67, 140, and 1500 m was located east of Nova Scotia for nine days in June 1975. In the frequency band 1-30 Hz, energy partition and coherence of signals from lines of SUS charges, from air-gun impulses from a seismic survey vessel, from background noise produced by natural sources such as wind-waves, swell, and earthquakes, and from oil-well drilling activity and passing ships are interpreted in terms of propagation in the water/sub-bottom waveguide including possible effects of instrument configuration on current-induced noise and signal distortion.

3.4 Classification Techniques

OVERVIEW OF CLASSIFICATION TECHNIQUES

A. Eller
Naval Research Laboratory

Classification is a sonar function that comes after detection and that generally requires a more detailed understanding of the acoustic field than is required for detection. This talk identifies some of the unique aspects of acoustics in shallow water and identifies the primary technical problem in that environment as trying to recognize a desired target in the midst of overwhelming clutter from false contacts. It is suggested that the classification topic be addressed from the viewpoint of four technical areas, involving bearing resolution; estimation of target depth, size and speed; target echo characteristics; and reverberation characteristics.

AZIMUTHAL RESOLUTION

A. Eller
Naval Research Laboratory

The ability to resolve separate contacts is a first step in the process of classification. This talk identifies basic issues regarding how shallow water EVA influences bearing resolution by conventional beamforming and by high-resolution techniques and how it causes azimuthal spreading of a signal.

A CONCEPT FOR TARGET DEPTH ESTIMATION

C. Katz
Ventana Sciences, Inc.

For shallow water environments, both the spatial complexity of the hydroacoustic propagation and the signal arrival path diversity due to boundary interactions are strongly dependent upon the source depth. This dependence of received signal characteristics on source depth may be exploitable for target classification as surface craft or submarines. Where it is possible to establish a parametric relationship between the received signal characteristics and the target's depth and trajectory, the target depth would be estimated directly. Otherwise, the received signal characteristics would be evaluated by comparison with a set of synthetically generated characteristics where each member of the set represents a hypothesis for target depth and trajectory.

VERTICAL PROCESSING SONAR

E. Pipkin
Naval Coastal Systems Center

A description will be given of a new shallow water sonar concept that makes use of reverberation and multipathing rather than trying to reduce their degrading effects. By displaying echoes on a plot of range versus vertical angle of arrival, this concept offers several advantages over the conventional sonar approach: (1) better signal-to-reverberation ratio, (2) a real-time reading of what the shallow water environment is doing to the sonar beam, including the limitations it imposes on sonar operation, (3) approximate depths of targets are given, and (4) some degree of ahead-of-ship fathometry is given.

LOW ka AND RESONANCE STUDY OF TARGETS

L. Flax
Naval Coastal Systems Center

The major feature of the acoustic scattering function (pressure amplitude versus frequency) for elastic bodies in water is analyzed at wavelengths comparable to the size of the scatterer. Theoretical analysis of resonance effects due to scattering is compared to experimental results.

ACOUSTIC IDENTIFICATION OF UNDERWATER TARGETS

S. Numrich, N. Dale, and L. Dragonette
Naval Research Laboratory

All submerged targets exhibit elastic behavior when interrogated by sound waves. Significant advances have been made over the past few years in understanding elastic returns from solid bodies and shells. In any given frequency region, the sound incident on a shell can generate flexural and compressional waves in the shell wall. Once understood, these elastic waves can be exploited in determining not only the presence of a submerged body, but its size and shape as well. Target reconstruction using elastic waves obtained from a hemispherically end-capped cylindrical shell will be presented. Some primitive techniques for extracting target information in the presence of reflecting surfaces will be illustrated for both solid and hollow targets.

WAVEFRONT ECHOES AND COMPLEX RESONANCES FOR TARGET IDENTIFICATION

L. Felsen and E. Heyman
Dept. of Elect. Eng. and Computer Science/Microwave Research Institute
Polytechnic Institute of New York

Transient echoes from acoustic targets can be analyzed in terms of wavefront arrivals or in terms of complex (damped) body resonances. Wavefronts are useful diagnostic tools at early times when they can be individually resolved; they contain information about the detailed body shape but they are aspect dependent. Complex resonances as incorporated into the singularity expansion method (SEM) are useful at later times when the object as a whole has had a chance to respond to the excitation; they are aspect independent but less capable of identifying detailed target characteristics. Efforts have been made to push the wavefront scheme to later times and the SEM scheme to earlier times, but both approaches run into difficulties because they then require many wavefronts or many resonances, respectively. We have explored a hybrid scheme that combines wavefronts and resonances within a single format, in a well-defined combination that seeks to draw upon the advantages of each. The potential of this method for target identification will be discussed.

CLASSIFICATION USING HUMAN-LIKE REASONING

C. Eggen
Applied Physics Laboratory, University of Washington

Using conventional techniques, target detection in a shallow water acoustic environment may be limited both by interference masking a target signal and by the necessity of sorting through many false targets. The latter problem has been addressed with some success using traditional pattern recognition and decision making techniques.¹ However, increased capability is still necessary to achieve a level of success consistent with current Navy performance requirements. Use of human-like reasoning, in which acoustic signals are interpreted on the basis of a historical data base, recent observations, and some model of the acoustic environment acquired from ocean physics, appears to offer a possibility of supplying that increased capability. Even when only a historical data base is present, use of cluster recognition techniques developed for Artificial Intelligence (AI) application appears to offer advantages compared with more traditional techniques.²

A program should be initiated to develop basic methods using human-like reasoning for acoustic echo classification. This would involve two efforts. First would be an effort to determine the information to be exploited. In addition to traditional clues such as amplitude statistics and shape, an example of exploitable knowledge might be the frequency dependence of the signature. This portion of the program could be accomplished in large part by analyzing data that is currently available. The second effort would consist of developing methods for applying human-like reasoning. A projection of the processing capabilities that would be available in the late 1990's should be made and, based on that projection, Artificial Intelligence techniques currently under development would be reviewed for applicability. In particular, the feasibility of using a production system approach would be addressed. The AI technique most likely to be successful should be studied in detail by developing a prototype set of software.

¹G.E. Lord and J.L. Fish, "Torpedo Sonar Echo Classification, A Second Status Report (U)," APL-UW 8005, Applied Physics Laboratory, University of Washington, May 1980 (CONFIDENTIAL).

²C.J. Eggen, "Acoustic Echo Classification Using Nearest Neighbor and Interval Cover Techniques," Report to the Director, Applied Physics Laboratory, University of Washington, January 1983.

ARCTIC SHALLOW WATER PROBLEMS

G. Garrison
Applied Physics Laboratory, University of Washington

Nearly a third of the Arctic is less than 100 m deep and the Navy is becoming increasingly concerned about the threat from submarines operating in these ice covered, shallow seas. For arctic ASW operations, the important problems are the acoustic returns from ice keels, the scattering of sound by the rough under-ice surface, and the absorption of multiple reflections in the bottom sediments. These basic properties should be measured and modeled for use in evaluating ASW systems. A review of the field investigations and analyses at weapon frequencies by our arctic group shows the progress made to date.

SHALLOW WATER REVERBERATION-LIMITED CONDITIONS AND ACTIVE SONAR WAVEFORM DESIGN

W. Roderick and B. Cole
Naval Underwater Systems Center, New London Laboratory

Shallow water operations in the 1990's time frame and beyond will be performed with active systems that have important design features for search and classification against low Doppler targets. Features such as programmable transmit and receive front-ends will permit a wide variety of transmit waveforms for detection and classification in shallow water reverberation-limited environments. However, waveform design, classification clue extraction and performance estimation all require knowledge of both the target echo structure and the characteristics of volume/boundary reverberation. A shallow water acoustics program, with measurements conducted in the North Sea, is currently focused on resolving some of the environmental issues pertaining to reverberation and signal propagation that impact waveform design. Preliminary results of boundary reverberation obtained at low grazing angles and at sonar frequencies will be presented, along with plans for future shallow water reverberation/target measurements using complex waveform transmissions.

APPENDIX A

CONCLUSIONS AND RECOMMENDATIONS, SHALLOW WATER ACOUSTICS WORKSHOP (1982)

The purpose of the Shallow Water Acoustics Workshop held at the Naval Research Laboratory on 8, 9, 10 December 1982 was to review the Navy shallow water experience and problems in order to define a pertinent technology base program. The Workshop was sponsored by the Office of Naval Research (Code 425UA, Dr. Peter H. Rogers).

The mix of participants was quite broad, representing fleet operational units, Navy Systems Command projects, Laboratory test and evaluation, system development, exploratory development, modeling, measurement and data bases, and basic research. A broad review resulted which stressed interrelationships among systems and disciplines.

The conclusions and recommendations, then, were expected to be broad in scope. The interchanges resulting from the broad coverage of subject matter and the broad range of interests of the Navy personnel were beneficial to the participants, who could apply information directly to existing programs without waiting for follow-up action on the Workshop Recommendations.

Conclusions of the Workshop

The conclusions of the workshop stressed deficiencies in the following three Working Group areas: (1) Detection Systems, (2) Weapons Systems (torpedoes, mines, and mine countermeasures), and (3) Models, Measurements, and Data Bases. The deficiencies were classified according to active and passive sonar roles, and by three frequency regions corresponding to passive search (low), active search (middle), and weapons (high). Thus, characteristics relating to acoustic propagation and bottom interaction in the three frequency ranges, as well as localization and classification of targets, were prioritized. The interferences due to reverberation for active systems and noise for passive systems were included in specifying priorities. The single most pressing need expressed by all groups was for the design of a proper, efficient, and expeditious set of survey techniques which could give proper environmental acoustics information appropriate to new system design and current system use in strategic areas.

Overall Recommendations

The three Working Groups, having sifted through the material of the presentations and their own discussions, reported their summary findings and recommendations for a shallow water acoustics program. According to the consensus, there was a preponderant need for an accurate but practical environmental acoustic description. The following list gives recommendations that emerged, along with the number of times that they were mentioned:

| | |
|--|----------|
| 1. Environmental description for the design and optimal use of current, emerging, and future ASW systems in shallow water. | 15 times |
| 2. Target classification techniques. | 5 times |
| 3. Systems studies, including environmental simulation. | 5 times |
| 4. Signal-to-reverberation ratio studies. | 3 times |
| 5. Noise studies. | 2 times |

Although the tally might be weighted by the way the workshop was organized, the results were not unexpected. In any case, these recommendations will be considered in establishing a Research Option for Shallow Water Acoustics by the Office of Naval Research. They will also furnish a basis for a Technical Option for a Shallow Water ASW Program.

An unclassified workshop enlisting participation by the Basic Research Community including University Laboratories and private research companies as well as Navy Laboratories will be hosted by NORDA shortly at the University of Southern Mississippi. This workshop will furnish the scientific and technical base for the preparation of an ONR Research Option.

Recommended Thrusts by Working Groups

Detection Systems Working Group

- Environmental description for the design and optimal use of current, emerging, and future acoustic ASW systems in shallow water.
- High-resolution, advanced-waveform system performance in shallow water.
- Distributed systems.
- Target classification techniques.

Weapons Systems Working Group

Torpedoes

- Increase S/R ratio for detection.
- Characterize threat targets and false targets and develop classification techniques.
- Characterize reverberation and propagation.
- Develop simulation techniques that include environmental complexity.

Mine Development

- a. Transmission phenomena for intermediate and close range for spatially extended sources (target classification).
- b. Target echo phenomena in a low signal-to-noise or signal-to-reverberation environment.
- c. Medium-induced limitations on the acoustic parameters. Models for low-ka targets.

Mine Countermeasures

- a. Theoretical models for low-ka targets.
- b. Methods of reducing multipath problem.
- c. Methods of increasing signal-to-reverberation levels.
- d. Motion compensation by synthetic aperture.
- e. Multiple scattering studies.
- f. Partial coherence studies.

Models, Measurements, and Data Base Working Group

| <i>Environmental Acoustic Research</i> | <i>Top Priorities</i> | | |
|--|-----------------------|-----------------|-------------------|
| | <u><1 kHz</u> | <u>1-10 kHz</u> | <u>>10 kHz</u> |
| a. Seafloor geoacoustics | 1 | 1 | 1 |
| b. Surface scattering | - | - | 1 |
| c. Bottom scattering | 1 | 1 | 1 |
| d. 3-dimensional modeling | - | 1 | 1 |
| e. Coherence (boundary) | 1 | - | 1 |
| f. Signal fluctuations | 1 | - | - |
| g. Noise | 1 | - | - |
| h. Water column | - | - | - |
| i. Remote sensing | 1 | 1 | 1 |

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APPENDIX D
SURVEY TECHNIQUES--MINORITY REPORT
by J. J. Hanrahan (NUSC)

INTRODUCTION

Present survey techniques in use by NAVOCEANO employ explosive sources and omnidirectional receivers. In water depths of less than 1000 ft, it becomes impossible to resolve propagation and reverberation measurements into their more basic components, namely bottom reflectivity and bottom backscattering strength, respectively, because of multipath contamination. Both basic components are needed by the active sonar, weapons, and mine communities, whereas reflectivity is only needed by passive sonar users. Therefore, data on the two components need to be gathered over a range of frequencies from roughly 100 Hz to 25,000 Hz. However, the frequency interval from 4 to 20 kHz has secondary importance. Grazing angles of incidence of primary importance to these diverse applications range from about 30° to near 0° with the smaller angles being more important.

To date, NAVOCEANO has not been able to report either bottom reflectivity or bottom backscattering values for any shallow water area. The fleet, therefore, is handicapped in conducting operations in shallow areas because the data required for predictions--whether it be SHARPS, ICAPS, SIMAS, APPEL, or OMS--are simply not available. Sonar performance cannot be quantified nor can ship routes be classified into "good acoustic paths" or "poor acoustic conditions."

SURVEY OBJECTIVES

For selected shallow water areas of operational interest, gather data on bottom reflectivity and bottom backscattering for angles of incidence from 0° to 30° over the frequency ranges of importance for active sonars, passive sonars, torpedoes, and mines. The region from 4 to 20 kHz would appear to be unimportant over the next 20-25 years for fleet utilization.

EXPERIMENTAL PROGRAM

Develop techniques and associated apparatus for measuring in both an economical and a timely manner the two basic parameters of bottom reflectivity and bottom backscattering. Of necessity, this measurement will be made with highly directional sources and receivers and with high temporal resolution. The data must be processed in a manner appropriate for the intended application. This will take the form of "sonar simulators" in the manner employed by the Marine Geophysical Survey.

EXPERIMENTAL PROCEDURES

- (1) Develop techniques to unravel propagation and reverberation measurements into bottom reflectivity and bottom backscattering, respectively. These techniques must incorporate sensors and processors with high spatial and temporal resolution.
- (2) Adapt these techniques for acoustic survey purposes in shallow water where the survey would use:
 - (a) ships
 - (b) ships and off-board sensors
 - (c) aircraft.
- (3) Survey a site or two.
- (4) Model the data at the test sites to assess adequacy of understanding. If needed, improve models.
- (5) Predict performance for fleet systems at the test sites and observe fleet performance at the test sites for a typical sonar, torpedo, and mine.
- (6) If the previous step is satisfactory, incorporate the data bases and model improvements into both ship- and shore-based fleet prediction efforts.
- (7) Enlarge survey areas to embrace operational needs.

APPENDIX E
CLASSIFICATION TECHNIQUES--DETAILED WORKING GROUP REPORT

The objective of the classification program is to identify features of the target and of the shallow water acoustic channel that can be exploited to provide improved classification capabilities.

The following is a collection of the written contributions generated by the Classification Working Group.

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BACKGROUND

Previous shallow water acoustics research has emphasized individual programs in propagation, noise, and reverberation. The understanding of shallow water environmental acoustics obtained from these investigations, while not complete, has matured sufficiently that we may begin taking the next logical step--namely, the development of techniques for detecting, classifying, and locating submarines. The research program proposed here will begin a synthetic process, drawing results from a variety of individual programs, to investigate the classification problem. Emphasis will be placed on the limitations imposed and opportunities presented by the shallow water environment. In particular, the program will seek to identify those acoustical characteristics that distinguish a submerged submarine from surface and other false targets, noise, and other interferences, and that are least degraded by the highly variable and strongly distorting environment. The results will serve to identify gaps in our knowledge of target characteristics, acoustic environmental modeling, and appropriate signal processing techniques.

The multidisciplinary nature of the problem and the modest size of the program prevent the addressing of all shallow water ASW problems, which extend from the passive low frequency regime to high frequency active weapons frequencies. As a result the scope of this pilot program will be somewhat arbitrarily restricted.

Some of what we currently know and understand about shallow water acoustics is summarized as follows:

- (1) Where bottom properties are known, we can model TL fairly well and can predict the optimal frequency and range dependence of the filter. High frequency absorption mechanisms are not entirely clear. These include shear, roughness, etc.
- (2) Eigenvalues and eigenfunctions appear to be determined by local properties in range dependent environments. Mode adaptation appears to result.
- (3) The loss of coherence in the vertical plane is most likely treatable as interferences among coherent modes.
- (4) Horizontal coherence is good up to perhaps 100λ --the limit is not clearly established.
- (5) The spatial spectrum of signal fading is qualitatively understood.
- (6) Dispersion curves for individual modes are verified by experiment.

CLASSIFICATION--BASIC CONCEPTS

The purpose of this introduction is to define the scope of the classification topic and to outline technical areas that could be part of a 6.1 research option devoted to the topic. Some of these technical areas will be discussed in greater detail by the speakers that follow, and I will address those areas not otherwise covered.

Two types of acoustic signals are germane to this discussion. These are (1) characteristic noises, both broadband and tonal, emitted from distant objects and (2) echoes from distant objects of acoustic signals generated by a known source. In each case one is receiving signals coming from some distant object.

Classification can be regarded as a later stage in the reception and processing of acoustic information, coming after the initial stage of detecting the presence of the signal. Definitions that help distinguish detection from classification, as used in the present discussion, are as follows.

Detection means that some property of the received and processed signal exceeds a preselected threshold.

If the threshold is crossed because of a spontaneous fluctuation in background noise, then the would-be detection is a false alarm. On the other hand, if a valid detection is caused by an object rather than the desired target, it is a false contact or false target. The distinction between background noise and false contacts often is obscure, as for example with shipping. Distant shipping contributes to background noise, but nearby shipping can be either noise or false contacts, depending on circumstances.

Classification means the process of determining whether or not a detection corresponds to a target of interest, and the gathering of any information that can assist in this determination.

Classification need not always imply a complete identification of an object. In many cases all that can be accomplished is to perform a partial categorization based on such questions as

Is the contact a single object or a group of objects?

Is the contact at the surface, within the water column, or on the bottom?

Is it at rest or is it moving?

Let us consider next what role is played by the environment and, in particular, what is special about shallow water. Shallow water environments present unique characteristics from three points of view.

- (1) Acoustic propagation conditions in shallow water are unique. The bounded, highly reverberant environment gives rise to extensive multiple propagation paths as well as severe time and frequency distortion. In addition, sound speed profiles, bottom properties, and the resulting acoustic propagation losses are highly variable and are generally unpredictable from one region to the next.
- (2) Background contamination, or clutter, in shallow water is unique. Shallow water areas often have higher background noise levels, higher densities of background scatterers, and a correspondingly higher number of false contacts from commercial shipping, rocks, and other causes.
- (3) Applications of acoustics in shallow water are unique. Typically one is trying to find objects that are at rest on the bottom, that are located near a scattering boundary, or that are moving slowly in the water. Consequently, the use of Doppler processing to discriminate against stationary reverberation is less effective.

In summary, the primary technical problem posed by the shallow water environment is that of being able to recognize a desired contact in the midst of overwhelming clutter from false contacts. This is largely a problem of resolving and sorting out the several contacts--in other words, a classification problem. This problem is made especially difficult in shallow water by the multipath arrival structure, the highly variable loss, and the unique background environment found there.

As a tentative first step it is suggested that a 6.1 research program addressing classification in shallow water be built around the following four technical areas:

Influence of shallow water environment on azimuthal resolution

Influence of shallow water environment on estimation techniques for contact depth, speed, and size

Influence of shallow water environment on target echo characteristics

Characteristics of background noise and reverberation in shallow water.

INTRODUCTORY REMARKS

For the purposes of this proposal we note at once that the classification problem drives the associated problems of modeling, environmental acoustics, measurements, and survey techniques. This is ultimately the case for shallow-water acoustics, although it applies to lesser degrees in the better understood, deep water regimes. Similarly, the ultimate application dictates the structure of the classification process itself, as well as specifying the needed physical models and parameters. Thus, the proposed research effort is strongly influenced by the competing demands of the potential applications and our need to exploit the complexities of the shallow water environment. The investigation, accordingly, must carefully take these facts into account, and be open to the real potential for innovative approaches and interdisciplinary methods.

PROBLEM SCOPE

The shallow water acoustics problem is compounded by the wide range of Navy systems that must operate in this environment. In order that the technology issues may be clearly identified, an attempt must be made to identify the different regimes that dominate the physics of the problem.

A simple 2×3 matrix that may be formed is shown in Table 1. Verified models of both the signals and noises (including propagation degradation) will establish the limits to which signal processing techniques (including multisensor modes) may be able to discriminate the signals from noise in a shallow water environment. Many elements shown in this matrix have been extensively studied (both analytically and experimentally) and will gain little from further study in this research option. There are several notable areas, however, that may offer significant new insights.

THE SHALLOW WATER ACOUSTIC ENVIRONMENT

The shallow water acoustic environment is an especially difficult sonar scenario; when one is concerned with the particular aspect of target classification, the scenario becomes even more difficult, and is a major problem area facing the Navy today. There are several environmental factors that are unique to this environment:

- (1) Bottom reverberation
- (2) Multipathing, which degrades target echoes and compounds the reverberation
- (3) A greater variability of environmental parameters, especially those involving the ocean bottom and the sound velocity structure.

Table 1. Shallow water classification matrix.

| ACOUSTIC FREQUENCY RANGE | High Frequency (medium to short range) | Low Frequency (long range) |
|--------------------------------|--|--|
| ACOUSTIC MODE | $f > 1.5 \text{ kHz}$ $\lambda > 1 \text{ m}$ | $f < 1.5 \text{ kHz}$ $\lambda > 1 \text{ m}$ |
| ACTIVE | <u>Signal:</u> Target highlights extensively modeled (geometric scattering) <u>Noise:</u> Reverb { surface } coherent bottom } incoherent volume } Biolog { B. Band False Targets } known | <u>Signal:</u> Target scattering mech. Poorly known. <u>Noise:</u> Multipath { surface Effects bottom Coherent (unknown) Incoherent (known) |
| PASSIVE | <u>Signal:</u> Br. Band Charact. Source Bandwidth Level vs Speed } <u>Noise:</u> Biolog. Shipping Wind } coherence bandwidth directionality | <u>Signal:</u> Br. Band char. unknown Narrow band char. known <u>Noise:</u> Shipping (known) Bottom Surface { coherent incoherent (known) |

Typical Medium to Short Range Systems:

Torpedos
Hull mounted sonars
Mine hunting sonars

Typical Medium to Long Range Systems:

Air deployed sonobuoys or arrays
Towed arrays
Surveillance systems

The Navy needs a greater capability for target classification in the shallow water acoustic environment. To obtain this capability, it must: (1) increase its knowledge of the above environmental factors and their acoustical interactions, (2) increase its knowledge and understanding of target echoes, especially in the low- κ range where target resonance effects occur, (3) seek and find some means of real-time assessment of the environment, especially the determination of what the environment is doing to the sonar beam and what limitations it is imposing on the sonar at a given time, place, and azimuth. To do this properly, the Navy must approach each of the above objectives both from an experimental and a theoretical point of view, developing and understanding more and more complex models in this process. Details of implementing such a program are given below.

INTERFERENCE AND ENVIRONMENT

The shallow water sonar problem differs from that found in deep water in a number of important aspects. The proximity of the ocean bottom precludes the long range propagation paths found in deep water, thereby making the problem a local one. This restriction to a locality, combined with the geographic variability of the continental shelves introduces a detection and classification problem complicated by a great variety of different types of interference and environmentally controlled propagation phenomena.

Depending upon the frequency range considered, the following incomplete list of sources of interference may be considered as sources of noise (N), false targets (F) or reverberation (R):

Wind driven waves (N,R)

Volume inhomogeneities in water (F,R)

Ice (N,F,R)

Shipping (N,F)

Bottom inhomogeneities (F,R) (includes topography and composition)

Biological populations (N,F,R)

Shore-based noise sources (industrial, surf).

These sources of interference depend not only on location, but in many instances on time.

Environmental effects on propagation include effects of the proximity of the ocean bottom, which are most conveniently grouped by frequency regime. At low frequencies (<1000 Hz), we have dispersion and

multipath propagation effects that distort the temporal waveform, the bandpass effect of the shallow water duct, and poorly understood influences of the boundaries on vertical and horizontal signal and noise coherence. At high frequencies, boundary roughness introduces scattering and frequency spreading. For many areas of practical naval interest the above environmental effects on propagation show a strong range dependence, even over the short propagation paths that need be considered.

This section of the program will focus on the influence of the interference and propagation effects peculiar to shallow water on the acoustic detection and classification of submarines. It should be recognized that these effects may offer advantages to be exploited as well as complications to be overcome.

TAKING ADVANTAGE OF COMPLEXITIES

No one can argue against the fact that we have deficiencies both in the various technologies and the data bases in shallow water acoustics. We must continue to increase our knowledge of shallow water acoustical and environmental interactions, such as reverberation, multipathing, etc. But we have to be careful that our approach to the problem does not lock us into an orbit that increases our information but never addresses the point of solving the operational problem. At some point we must address the question: How do we use all of our gathered information in some technique that will actually classify echoes? At one extreme, there could be a vast computer algorithm that would take a digital approach of artificial intelligence and that would weigh various inputs from targets and environments and compute the needed probabilities. It may not be possible to do this in real time. On the other extreme, an analog approach could provide displays of condensed information to aid the operator in making the decision. Preferably, this information would be obtained in real time using an acoustic probe, since the environmental factors in shallow water vary considerably with changes in time, place, and azimuth. In both of these extremes we are making use of the complexity of the shallow water environment to provide the maximum amount of information on which to make the classifying decision.

CLASSIFICATION CONCEPTS

Successful classification requires a proper combination of physical modeling and appropriate signal processing. The main goal of modeling here is to provide tractable analytic expressions for the desired signal fields and waveforms (and their relevant statistics), which in turn are needed in the specific classification process. Equally significant are the models of the interference (i.e., "noise") fields and received waveforms. These are necessarily statistical-physical models. Thus, for the desired signals we require, at least, the analytic representation of the following for both the field and the signal sensed by the array:

- (1) Propagation effects: spreading loss, multipath structure, boundary interactions, medium inhomogeneities, etc.
- (2) Doppler effects
- (3) Fading--which is generally time-dependent and often inhomogeneous
- (4) Harmonic structure (spectrum).

On the other hand, for the noise we need at least the first order probability density (pdf) of field values, and at least their space-time mean values and covariance functions. A critical feature of real world interference is its frequent highly non-Gaussian character; i.e., the noise often has a large, structured, but effectively random, component as well as an accompanying Gaussian contribution. Conventional receiving systems, namely those designed to operate (nearly) optimally in normal noise (the well-known "matched filter" receivers), can be severely degraded (typically 20 to 50 dB) when used in highly non-Gaussian interference, particularly in the critical limiting situation of weak or threshold signals, where the desired signal is often well down in the noise.

Classification itself requires a combination of signal detection and signal waveform and/or parametric extraction (i.e., estimation). Threshold operation, and especially optimum threshold operation, requires processing algorithms that are explicit (and usually nonlinear) functions of the first and second (covariance) moments of the signal, and the first order pdf of the noise; hence the central importance of adequate physical modeling noted above. [Threshold systems lose their optimal character for larger input signals, but are, of course, absolutely better as signal level versus noise is increased, so that establishing a receiver design (= processing algorithms) for the optimal threshold situation yields effective processing with these same algorithms at stronger signals.]

A key element of signal processing here is spatial sampling, as well as sampling in time. Effective sampling plans are those--where and when possible--that achieve independent noise samples and still maintain the waveform coherence of the desired signal. To establish this possibility we need at least the covariance function of the signal and noise fields over the array in question--hence the requirement for modeling (as well as measurement) of the space-time covariance function of the interference field.

Finally, our goals here are to determine--i.e., "classify"--desired signal sources (or targets) in the shallow water acoustic environment. Among the specific target features that are ultimately to be obtained and distinguished from false targets are:

- (i) speed
- (ii) location (range, angle)
- (iii) depth
- (iv) cross section
- (v) orientation
- (vi) size
- (vii) structure (complexity and highlights).

At this point we emphasize that in recent years considerable progress and many new results applicable to both (1) the modeling of the signal and interference, and (2) the appropriate signal processing, have become available for an attack on our problem here.

We stress, in addition, the adaptive nature of the signal processing demanded here, and the potential of, and probable need for, signal design, i.e., selection and use of effective integrating signal waveforms.

Reference Material:

D. Middleton and A.D. Spaulding, "Optimum Reception in Nongaussian Electromagnetic Interference Environments," Tech. Rpt., approx. April 1983, Inst. of Telecommunications Sciences, Natl. Tel. Com. & Info. Admin., U.S. Dept. of Commerce, Boulder, Colo. 80303. Note: The analytic results and models can be carried over directly to the corresponding acoustic problem here. Also see the references in this report for relevant journal and report articles.

D. Middleton, "Multi-Element Threshold Signal Detection of Underwater Acoustic Signals," NOSC Tech. Rpt., March 1983. Also see references therein. This report has a strong emphasis on signal and noise modeling, as well as spatial sampling and optimal detection.

D. Middleton, "Threshold Signal Reception in Electromagnetic Interference Environments: Part III, An Introduction to Canonical Threshold Signal and Parameter Estimation," NTIA Rpt. CR-83, March 1983, U.S. Dept. of Commerce, Boulder, Colo. 80303. This report gives new results on optimum threshold extraction algorithms.

D. Middleton, "Doppler Effects for Randomly Moving Scatterers and Platforms," J. Acoust. Soc. Am. 61(5), 1262-1267, May 1977.

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PROGRAM PAYOFF

Target classification in shallow water is a key facet of coastal defense, ASW surveillance, mine countermeasures, and weapon deployment. Knowledge gained in identifying and studying target classification techniques that exploit the special complexities of the shallow water environment is going to encourage sonar development efforts in formulating realizable implementations of these techniques.

Specifically, in the short-term, by estimating the performance bounds of each potential classification technique, it should be possible to identify high payoff techniques for which extensive long-term investigation is justified. Where preliminary findings indicate that a generic technique has limited merit, the further expenditure of resources can be avoided by collateral 6.2, 6.3, and 6.4 activities.

Ultimately, there are significant transition possibilities in the areas of transducer design, signal data communications, capability for real-time embedded propagation predictions, and sonar system architecture. All of these areas may be influenced if revolutionary, rather than evolutionary, approaches are required for shallow water target classification.

RECOMMENDED PROGRAMS

The problems to be identified in the suggested research program require both measurement and modeling efforts and innovations in processing. In terms of modeling, some areas in which additional effort seems appropriate are reverberation and interference statistics, reaction of true and false targets to interrogation by a variety of signals, and the passive fields of both true and false targets. The latter two areas should include depth dependencies. An additional question of interest is the effect of propagation on the character of both true and false target signatures.

Innovations in processing are required in terms of probing the environment and adapting signal and search tactics to take advantage of the environment. Methods of optimizing the signal processing to take advantage of projected properties of the target signal are also necessary. Measures of the characteristics of true and false targets, and methods to derive those measures from the data, are also required. The ideal output of this process would be very robust measures of the character of the source of an acoustic signal. It is possible that no single very-robust feature will be found. In this case, significant gains may be made in techniques of pattern recognition or AI that blend many sources of information, that sense inadequacies in information and request more data, and that draw appropriate conclusions.

Particular research areas identified as being likely to give valuable results are (1) models of interference statistics and their connection with the physical environment, (2) models of spatial coherence properties of the interference field as a function of propagation, (3) development of high frequency active metrics related to the roughness of an ensonified object, (4) high and low frequency measurements relating to target depth and azimuthal extent, (5) signal designs that take advantage of acoustic features, (6) low frequency active measurements of target classification characteristics, both full-scale measurements in the field and reduced-scale tank measurements, (7) similar measurements of false targets, and finally (8) methods of interpreting features of a signal in light of environmental and tactical information.

SUMMARY OF GOALS

This research program will provide performance bounds for, and mathematical relationships among, the key parameters of a physically-based classification approach. This program is specifically tailored to exploit the diverse special features of shallow water environments. The goals are accordingly twofold: (1) to obtain effective discrimination between desired targets and all other contacts, and (2) to furnish realizable classification procedures to 6.2 programs.

RELATIONS TO OTHER EFFORTS

Classification may possibly be achieved through use of active systems in the 100-1000 Hz band in shallow water. They offer the following potential advantages:

- (1) Acoustic propagation is relatively good, though coherence of the propagation in areas of strong bottom interaction is an issue.
- (2) Target strength is difficult to reduce through coating techniques.
- (3) Processing data rates are relatively low.
- (4) At least three experimental devices will have matured by FY85, sponsored independently by DARPA, NAVELEX 612, and NORDA.
- (5) Small scale variations in the environment do not significantly modify the propagation.

- (6) Doppler shifts are low so that some processing techniques can be implemented without frequency shifting. On the other hand, dispersion is higher than at higher frequencies, but the resulting signal distortion can be handled in the time domain.
- (7) Scattering from targets of interest may be resonant and thus would contain identifiable target information, by class.

Research Option Objective: To determine environmental limits in active and passive acoustic detection and classification of targets in shallow water. These limits may be due in part to both available technologies for possible system implementation (e.g., fiber optics for sensors and transmission lines; AI for feature extraction) and the knowledge base of environments themselves and the factors that are key in setting the limits. Clearly, these limits are in the context of which schemes are to be employed for detection and localization; it is hoped that new schemes matched to the environment would evolve from the pursuit of the objectives.

PROGRAM REQUIREMENTS FOR TARGET ECHO

In order to classify a target it is essential to know a priori how the target will respond to interrogation by an acoustic pulse of specific duration and frequency content. While the acoustic characteristics of any given target are not dependent upon the shallow water environment, the features of the target echo that are exploitable as classification tools will be enhanced or degraded by the reverberation and propagation characteristics specific to the shallow water regions. Any cohesive program that would seek to impact on shallow water target classification must include the following:

- (1) Efforts to delineate exploitable target features for long and short range detection/classification.
- (2) Some quasi-analytical estimate of the amount of signal degradation and dispersion that can be tolerated before specific features cease to be discernible.
- (3) Attack angle dependent characteristics that can be used in multipath propagation environments to provide additional target discriminators.
- (4) Choice of optimum frequencies and signal conditioning for various shallow water detection/classification scenarios.

- (5) Sufficient knowledge of false targets to allow reliable classification.

In order to have a reasonable chance of success in any of these areas, specific task areas must be addressed.

In all appropriate scenarios, there must be propagation and dispersion models that set limits on the nature of echo characteristics that can persist and be exploited. Both temporal and spectral features must be considered, as correlation and other signal processing techniques can be presumed to exist in both time and frequency space. To optimize the detection/classification procedures, distributions of sensors in both the horizontal and vertical should be considered. Attempts to resolve the depth of a target are very important. Placement of such sensors must be directed by the best possible knowledge of the environment.

For any selected scenario, the physical mechanism causing unique target characteristics should be examined in detail. Resonances, hull vibrations, significant self-noise, effects of highlights, and internal structures should be examined as "robust" classifiers. Characteristics that distinguish various classes of targets from each other and from false targets (ice ridges, oil drums, convergence zones, biological clutter, etc.) are of particular importance. Target strength information alone is not adequate.

All of these tasks should be initially addressed by modeling efforts. The results of these studies and experiments should be employed in selecting sites of validation tests, preferably on full scale targets. The sea trial should be designed as a test bed for the best predictive models developed jointly by both target and environment experts (if not jointly, at least in close collaboration).

While ultimately the targets of interest are usually considered in the 6.2-6.3 arena, the issue of specific characteristics is not generally investigated in detail by that community. There are a number of mechanisms that require basic research--exploitability of resonance; plate waves, and scattering of plate waves by internal structures; Bragg diffraction by periodic support structures; what remains after coating, etc. Since the final end of the classification effort is a traditionally 6.2 target, perhaps the sea trial would have the most impact if such a target could be used for at least part of the tests.

Perhaps the surveillance frequency regime would be a bad choice for shallow water trials. It is a region in which the target has the fewest exploitable features. Maximizing potential success suggests something in the 1-4 kHz region where wavelengths are small enough to pick out individual features, coatings are not yet fully effective, and plate waves can be generated on some regions of the target.

ENHANCEMENT OF DETECTION AND CLASSIFICATION SYSTEM PERFORMANCE BY USING PROBES AND MODELS TO DECONVOLVE CHANNEL RESPONSE

Many sonar systems use a matched filter approach that correlates received signals with a replica of the transmitted signals. In the shallow water multipath environment, interference effects so distort the received signal that it no longer resembles the transmitted signal. In this situation the optimal performance of the matched filter can be obtained only by correlating with a replica of the received signal, and hence knowledge of the broadband transfer characteristic of the channel is required.

In general we do not know if we can predict the channel response function accurately enough to improve system performance. Nor do we understand the relative importance or required precision of shallow water environmental inputs to models. Surely, at very long ranges interference reaches saturation, and there is little hope of improving performance. However, at intermediate range the possibility exists of determining the channel response function by use of acoustic probe signals. There are many ingenious ways to implement probe signals (time-gated reverberation from active sonar, reception from distant hydrophone or sonobuoys, etc.).

Information from probes can be combined with a model or inverted to measure the environment (sound-speed field, bottom, etc.). In application, this probably can be accomplished clandestinely by use of broad spectrum, low level pseudorandom transmission.

In general, modeling and measurement of broadband shallow water transmission for various environments have not been undertaken. We don't have a data base or model comparison to allow for prediction of the performance enhancement by these methods. The randomizing effect of the shallow water channel on broadband transmission must be studied in detail and specifically in the region of low- k_a type scattering (500-2000 Hz). All necessary tools are at hand to conduct such a program. Many narrowband coherence propagation models can be readily extended to the broadband case. Data acquisition and analysis with the existing equipment is straightforward. Rapid development of microprocessors and FFT boxes makes possible shipboard implementation of probe/model signal enhancement if the research proves the methods feasible.

DETAILED PROGRAM PLAN

Yr. 1: Set stage

Choose candidate targets
Pinpoint specific frequency regions
Options: 100 Hz - 10 kHz

Perhaps mount one or more regions as sea trial targets.

A. Environmental

1. Identify modeling requirements.
2. Start time domain modeling with focus on accurate predictors for target extraction.
3. Select candidate experimental sites.
4. Employ prior data relevant to option needs.
5. Review reverberation prediction status.
6. Select candidate waveforms.

B. Target

1. From existing data base and possibly one more (diesel electric), select class and target specific characteristics.
2. Calibrate target characteristics in free field.
3. Identify productive comparison regions.
4. Select radiated noise character for passive detection.

C. Plan preliminary experiments, aperture selection

D. Artificial intelligence--begin to tie in at level of waveform and feature extraction

Yr. 2: Aim for early in year, simplified "test" experiment to test complex waveforms (broadband signal format) on a simple, well-known target or transponder.

Concomitant Tasks

Identify hardware/processing needs--beg, borrow, or procure.

Employ several reverberation models for signal waveforms selected.

Time domain model ready for test of replica correlation concept.

Environmental support.

Experiment

Fixed target/receiver, several ranges, broadband signals, reverberation spectrum, fluctuations, simple target or emitter with appropriate waveforms, extract scattering function and ambiguity function for environment.

Test capability to predict received time signature.

Data analysis

Hardware procurement

Expected results will be in a "transfer function" form that allows convolution with various waveforms and target characteristics

Full scale experiment design

AI concept development continuation

Simulation model development--simulate a test-bed experiment

Include input from tank experiments

Yr. 3: Full scale simulation test (first half yr.)

Finalize experimental design

Identify model deficiencies

Exercise model for several cases

Refine data analysis and processing schemes

Hardware reengineering and procurements

Include input and trials from tank experiments

Examine adaptive techniques as option to pure signal processing

Sea test (first half yr.)--engineering trial or full scale level with frequencies and depths decided. Preliminary emphasis on equipment and procedures--allow some data taking.

Major Experiment I

Late summer Yr. 3 (two-platform experiment)

Environmental support

Piggyback with other working groups

Active and passive

Yr. 4: Major Experiment II, spring.

Careful environmental support--presumed in line with other working groups

Simulation refinement (tank refinements)

Analysis of data from the two experiments

Yr. 5: Data analysis and documentation

Assessment

Model sufficiency

Model usefulness

Waveform designs

Signal processing

Concept

Environmental limits on classification

Documentation

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| A Shallow Water Acoustics Workshop was held at the University of Southern Mississippi Gulf Park Campus, 9-11 February 1983, under the sponsorship of the Office of Naval Research (Code 425UA, Dr. P.H. Rogers). The Naval Ocean Research and Development Activity was the host organization. The purpose of the Workshop was to help develop a research program plan in shallow water acoustics. The objective of this Workshop was to formulate an approach to answering a number of specific questions about the characterization of the | | |

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acoustic environment and acoustic classification techniques. The Workshop was organized into three Working Groups: (1) Environmental Acoustics and Modeling, (2) Measurements and Survey Techniques, and (3) Classification Techniques. About 39 papers in all were presented under these three headings prior to the Working Group sessions. Each Working Group prepared an outline of a recommended 5-year plan that included estimated funding profiles.

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